Anbar Journal of Engineering Science (AJES) **Vol. 16 , No. 1 (2025) , pp. 1 ~ 12**
P-ISSN: 1997-9428 ; E-ISSN: 2705-7440 DOI: http://doi.org/10.37649/aengs.2025.153712.1103

University of Anbar

Anbar Journal of Engineering Science

journal homepage: https://ajes.uoanbar.edu.iq/

Performance Enhancement of Electronic Chipset by the Successive Cooling System

Ali D. Salman[a]
[a]*Mechanical Engineering department, University of Technology- Iraq, Baghdad, Iraq*
Ali.D.Salman@uotechnology.edu.iq; https://orcid.org/0000-0003-2742-1852

PAPER INFO

Paper history
Received: 19/09/2024
Revised: 14/11/2024
Accepted: 01/12/2024

Keywords:
Hybrid Cooling system
Intercooling cylinders
Thermoelectric cooler
Central processor unit
Graphical processor unit

ABSTRACT

The performance of electronic devices, especially computers, depends on the efficiency of the electronic chips and Computer processing units, which are mainly made of semiconductors, so their working efficiency is inversely proportional to their working temperature. Therefore, this paper presents an experimental investigation of the design, implementation, and testing of three cooling systems to maintain the temperature of the processing unit as minimum as possible. The first is a traditional system dissipates heat from the working fluid to the air through a finned tube heat exchanger. The second successive hybrid system was designed to integrate with the first one in addition to a thermoelectric cooling system to cool the working fluid. The third system included in addition to the traditional heat dissipation one, an intercooler cylinder with a large quantity of the working fluid in the main system beside a separate system for cooling the working fluid using thermoelectric cooling to ensure sufficient cooling of the processing units when working at high frequencies by providing a large capacity of working fluid pre-cooled to a low temperature. Comparing the experimental results of the cooling systems with the traditional one under the same test conditions showed that the second system led to a reduction in the temperature of the processing unit by 5.2%, while employing the third system reduced the temperature to 11.3%., When the thermoelectric cooling unit operates at a performance factor of about 1.76.

1. Introduction

The performance of electronic devices, particularly computers, depends on the performance of electronic chips, CPU and GPU, since these units are considered sources of heat, which negatively affects their performance and thus negatively affects the work of electronic devices, so there was a need to cool these electronic parts to maintain their performance and prevent damage. Many companies, centers and research institutions have provided experimental and numerical research to solve this problem by providing multiple and innovative types of cooling systems. Most of the research presented in this field has relied on employing traditional cooling types (forced air-cooled heat sink) as a basis comparison when combining other types, comprising cooling systems (water-air), heat pipes, and thermoelectric cooling, while utilizing cooling liquid containing nanoparticles. The research group presented

* Corresponding author: Ali D. Salman; Ali.D.Salman@uotechnology.edu.iq ; +964 770 295 0477

water-air cooling systems using nanomaterials to improve heat transfer by increasing the heat capacity of the liquid and improving its density [1]. In this experimental study, two models of coolers were presented that operate on the principle of immersing processors in a phase-transformed substance to absorb the largest amount of heat, thereby lowering the temperature of the central processor. This also leads to a reduction in the energy spent on cooling compared to the traditional method. The results also showed that the direct contact is the most convenient and least energy-efficient method [2]. Many studies have shown the possibility of using a thermoelectric cooling system directly or a water-cooling system to cool electronic chips, CPU and GPU. These studies highlighted the significance of considering both the type and number of semiconductor pairs and determining the the unit's capacity. It was recommended that it work at the highest performance and not at the highest thermal capacity [3]-[7]. A model of the behavior of the heat transferred from a tablet was tested using the COMSEL optimization module, by employing moving asymptotes as an algorithm to improve heat transfer. In practice, three heat sinks were made of aluminum (reinforced and non-reinforced) with a basic heat sink in the shape of the letter L. The results showed that the designed heat sinks successfully dispersed heat efficiently [8]. Studies have also demonstrated the potential use of a heat pipe or a heat pipe without a wick (thermosiphon), either through direct return or through a loop, with high efficiency in dispersing heat. This heat exchanger relies on the latent heat of evaporation to extract heat, allowing it to be dispersed over a large area from its source. In practice, three heat sinks were made of aluminum (reinforced and non-reinforced) with a basic heat sink in the shape of the letter L. The results showed the designed heat sinks' success in efficiently dispersing heat [8]. Studies have also shown the possibility of utilizing a heat pipe or a heat pipe without a wick (thermosiphon), either direct return or through a loop, with high efficiency in dispersing heat. This type of heat exchanger relies on the latent heat of evaporation to extract the heat, allowing it to be dispersed over a great area from its source. The system is acceptable, considering the quality of the working fluid, the filling ratio, and the number of tubes used [9]-[19]. These numerical investigations demonstrated that employing foam matrix to the inner fins of the water-cooled exchanger leads to improved cooling of electronic chips, as the results showed an improvement in heat release by a rate of 50% [20]. A numerical study of a miniature system for cooling electronic chips using a microchannels exchanger, where the heat was removed using a vapor pressure system operating with refrigerant R134a. In addition, the Fluent program was employed to analyze the heat distribution between the central processor unit and the cold surface, showing acceptable accuracy [21]. A numerical study showing the effect of the air temperature of the test environment on improving the cooling of the electronic memory card. It was found that the heat transfer coefficient is directly affected by the ambient temperature, which affects the operation of the integrated cooling system [22]. To improve heat management, a hybrid cooling system was designed to improve cooling procedures by regulating the withdrawal and release of heat from the phase change material, which was reinforced with a porous metal to increase the heat capacity relative to the volume, and to remove heat, a heat pipe was added to accelerate the work of the cooling system, which achieved good results in its work [23]. An experimental study used a typical cooling system by circulating distilled water, adding 25% Arteco-Freecor solution, and releasing heat through the forced air. The results showed that the cooling of the central processor unit improved compared to cooling using the traditional system [24]. Based on the concept of an energy storage unit, this experimental study presented a practical design for a passive heat sink (HS) using phase change material (PCM) and adding in nanomaterials (NPCM) to cool electronic chips with a heat flow of 2000-4000 W/m^2. The results for both steady state and transient states showed that adding PCM to store energy reduced the temperature of the chips by 22 °C, and that the temperature reduction depends on the percentage of PCM [25].

2. The novelty of this work

This work aims to improve the performance of computer processing units by designing and manufacturing a hybrid successive cooling system that works on the dissipation of heat from the primary working fluid and cooling it through a successive intercooling cylinder that is cooled using a TEC system and operates within close to its maximum COP, using an intercooler cylinder to store large quantities of working fluid to avoid the sudden overheating of computer processor units when working at high frequencies.

3. Experimental setup

A main modular cooling system was designed and implemented to be innovative. It was then develoed into a hybrid cooling system in different patterns by adding a thermoelectric cooling system, a flat block heat exchanger integrated with finned heat pipes, and an intercooling cylinder, as shown in the schematic diagram in Figure 1.

3.1. Basic cooling system water-air heat exchanger

As shown in Figure 1, the developed cooling system consists of a central processor simulation unit consisting of an aluminum plate 3×3 cm ,1mm in thick, below which are strips of Teflon (a thermally conductive electrical insulator) with a PCB layer, and between them is an electrical heater wire 7.3 ohms, while a layer from the thermal gasket covering it. The heater was thermally insulated from all directions except the upper side. To cool the CPU simulation unit, a flat copper block water heat exchanger was used (2.5×2.5 cm with 1 mm thick), through which distilled water passes as the working fluid. Cold distilled water enters the heat exchanger, and the water leaves it after gaining heat to an air-water flat finned tube HE (16×12×2.7 cm), that was, the forced air driven by a DC fan (12×12 cm) works to remove heat from the water, then water leaves to digital flow meter, and then water drawn through a diaphragm reciprocating water pump that pumps the water and returns it to the flat copper block heat exchanger to remove the heat generated in the central processor simulation unit due to the temperature difference between CPU and water. As shown in Figure 1, the cooling system is equipped with DC power supply (APS 3005D), to feed electricity to the electrical heater at selective voltage applied, and another DC voltage regulator power supply (LM317_employ to feed electricity to the water pump No. -1, and the system is also equipped with an electrical power stabilizer (TM-1000 VA.C). The cooling system is equipped with a reader data acquisition, data logger system (Lab Jack U6 pro+CB37 terminal board) connected to a computer to read and store the temperatures of the CPU, the test-conditioned environment and the temperatures of the path of distilled water in the cooling system. The flat-block heat exchanger also has a differential digital manometer (HT-1890) to measure the pressure drop through it. To read the water flow rate through digital sensor YF-S401 (0.3-6 LPM), it connected to the PC by microcontroller Arduino mega-2560.

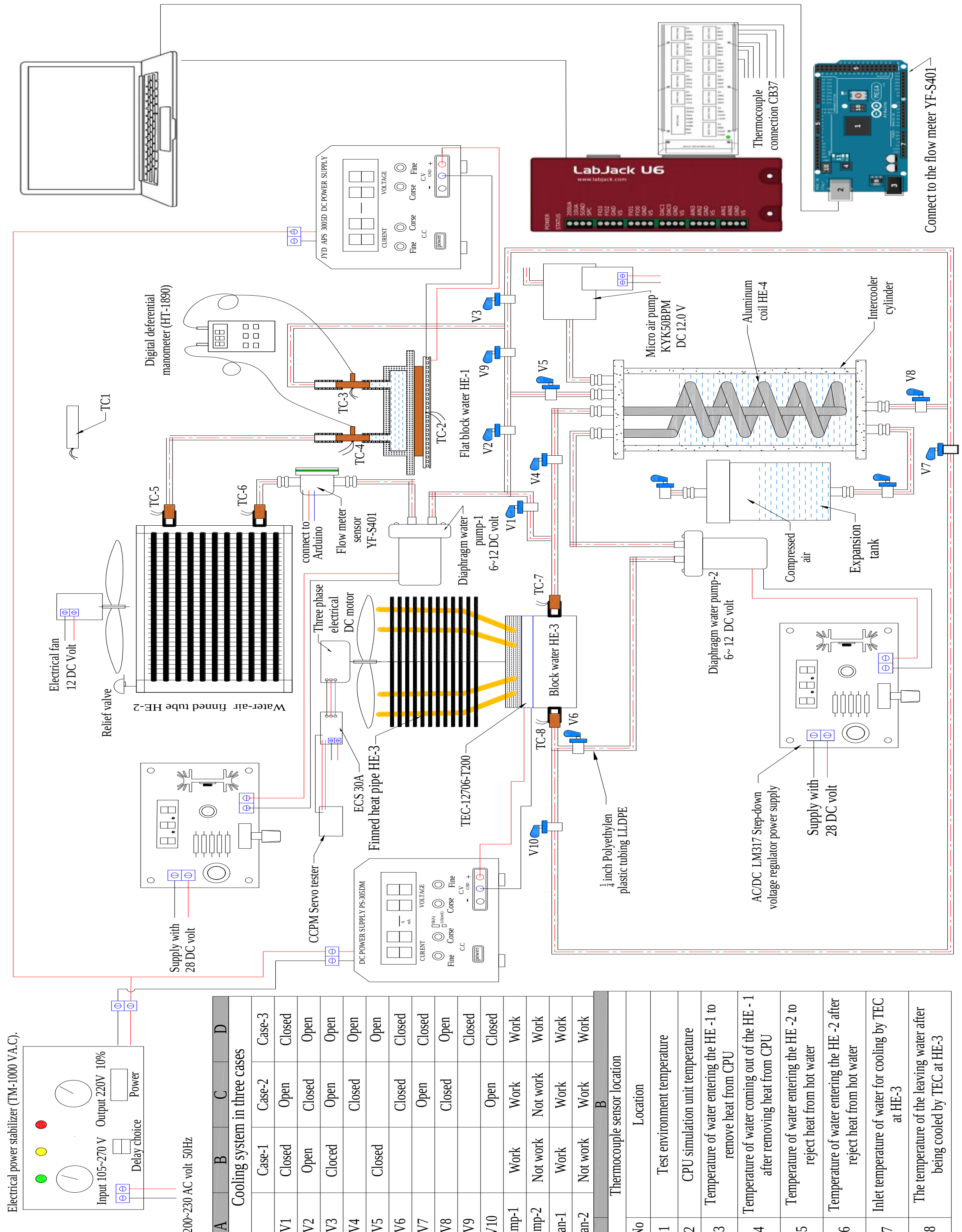
3.2 Modified hybrid cooling system (water-air-TEC)

To improve the performance of the basic cooling system used to cool the central processor simulation unit, a successive combined cooling system was added through which water passes after it leaves the heat exchanger (air-water). The combined cooling system consists of a thermoelectric cooling unit (TEC). The cold surface of TEC is connected to a block heat exchanger using a thermal paste (k=2 W/m. °C). The hot surface of the TEC is cooled through a cooling system of finned heat tubes integrated with a flat aluminum plate. The thermoelectric cooling unit was fed with DC voltage using Dc-power supply PS-305DM. A three-phase brushless electric motor was used using an electronic speed controller ESC and servo motor tester with three channels to remove heat from the finned heat pipe.

In this modified hybrid cooling system, water flows through heat exchangers successively. As the water enters the main heat exchanger to cool the central processor simulation unit, it moves to the heat exchanger (air-wate) to release the heat, passes though the block heat exchanger of the thermoelectric cooling system to cool it, and decreases its temperature, and then returns to the central processor simulation unit to cool it.

3.3. Modified hybrid cooling system (water-air/TEC-Intercooler cylinder)

Changes were made to the first developed hybrid cooling system by manufacturing and adding an acrylic intercooling cylinder (Di=5 cm, H=15 cm, wall thickness=0.55 cm) (Figure 1), which represents a change in the amount of working fluid in the central system within the flow path. So, it can be considered an accumulator tank for working fluids. An aluminum coil is inserted an into the cylinder. It is made of an aluminum tube with a nominal diameter of 0.652 cm and a length of 80 cm. The nominal diameter of the aluminum coil is 3.2 cm. The working fluid of the auxiliary system is cooled by using a thermoelectric cooling system that has been separated from the central system with the addition of a second diaphragm pump to circulate the secondary working fluid (distilled water) into the auxiliary system



	A	B	C	D
1		Cooling system in three cases		
2		Case-1	Case-2	Case-3
3	V1	Closed	Open	Closed
4	V2	Open	Closed	Open
5	V3	Cloced	Open	Open
6	V4		Closed	Open
7	V5	Closed		Open
8	V6		Closed	Closed
9	V7		Open	Closed
10	V8		Closed	Open
11	V9			Closed
12	V10		Open	Closed
13	Pump-1	Work	Work	Work
14	Pump-2	Not work	Not work	Work
15	Fan-1	Work	Work	Work
16	Fan-2	Not work	Work	Work

	A	B
1	Thermocouple sensor location	
2	TC-No	Location
3	TC-1	Test environment temperature
4	TC-2	CPU simulation unit temperature
5	TC-3	Temperature of water entering the HE -1 to remove heat from CPU
6	TC-4	Temperature of water coming out of the HE - 1 after removing heat from CPU
7	TC-5	Temperature of water entering the HE -2 to reject heat from hot water
8	TC-6	Temperature of water entering the HE -2 after reject heat from hot water
9	TC-7	Inlet temperature of water for cooling by TEC at HE-3
10	TC-8	The temperature of the leaving water after being cooled by TEC at HE-3

Figure .1.a. Schematic drawing of the basic and modified hybrid cooling system depending on the case of operation.

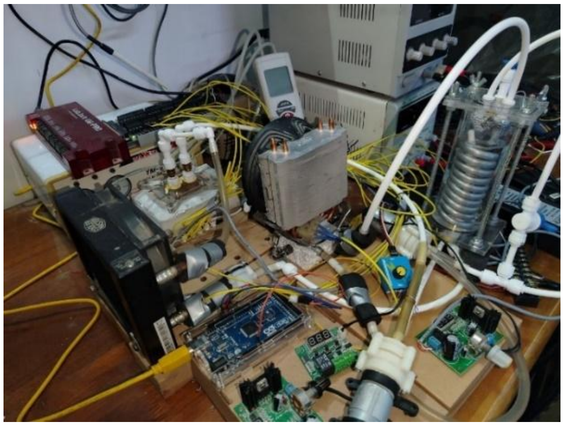


Figure 1.b. Photograph of the practical test device.

after cooling it to the coil that was inserted in the intercooling cylinder to cool the working fluid in the main system. This means that the fluid stored in the intercooling cylinder can be cooled before operating the computer or electronic system.

4. Test method

Basic tests of cooling systems were adopted to determine the values of test variables standard to the developed hybrid cooling systems. The value of the heat generated by the central processor simulation unit was determined by the voltages applied to the electric heater and within the capabilities of the power supply. Therefore, the values of DC voltages applied are 5, 10, 15, 20, 25, and 30 DC volts. The volumetric flow rates of the working fluid coolant (distilled water) in the main path of the cooling system are 22.5, 38.5, 52.5, 63.5, and 73 liters per hour. Within the tests of the first developed hybrid cooling system, all values applied to the main system are adopted, with constant voltage applied to the thermoelectric cooling unit at values of 6, 8, 10, and 12 DC volts.

For the second developed hybrid cooling system, the results of the first developed hybrid cooling system are adopted Figure 1, in addition to calculating the optimal performance factor for thermoelectric cooling and adopting the temperature difference measured between the hot and cold surfaces. Therefore, the flow rate of the working fluid for both the primary and accessory cooling systems was determined, as 73 lph. It also adopted a constant voltage of 6 DC volt depending on the temperature diffrence between the hot and cold sides and the heat rejection rate from the hot side in the TEC and its optimum performance.

5. The relevant calculations

The heat generated in the CPU simulation unit by multiplying the DC voltage applied and the measured amount of current passing through the electrical heater can be determined by employing (eq-1) [27]:

$$Q_g = V\ I \tag{1}$$

In (eq-1), assume that all electrical power (depending on the applied voltage and current drawn) will be converted into thermal power

While heat removed by flat block HE-1 can be determined using below equation [27].

$$Q_r = \dot{m}_w\ Cp_w\ \Delta T \tag{2}$$

In general, the amount of heat entering and leaving the system was calculated by adopting the values of the temperature diffrence to determine whether heat is added to or reject from the system, depending on whether the resulting signal is positive or negative.

$So\ \Delta T: represent\ temperature\ of\ working\ fluid\ outlet\ from\ HE\ minus\ temperature\ of\ working\ fluid\ inlet\ to\ the\ HE$. So (eq-2) can be re-written as;

$$Q_r = \dot{m}_w\ Cp_w\ (T_{w-o} - T_{w-i}) \tag{3}$$

The same thing applies to other heat exchangers, noting that in the HE-1, the heat generated by the central processor simulation unit is removed by working fluid. In the HE-2, the working fluid (distilled water) loses its heat by releasing it through that exchanger. As for the third heat exchanger, the working fluid is cooled within the block heat exchanger unit-TEC (Case No. 2). While in (Case No. 3), the working fluid in the main system is selected after heat is released to the intercooling cylinder to be cooled by the working water in the ancillary system. Where the water is cooled a thermoelectric cooling system.

Calculating the cooling capacity of the working fluid is directly through the block HE with thermoelectric cooling (Case No. 2) or indirectly via the intercooling cylinder (Case No. 3). Therefore, the calculation of the cooling capacity in (Eq-1), taking consideration the temperature. The result is negative because the fluid is being cooled. That is, the temperature value in HE-1 is positive (heat entering the system), for HE-2 the system releases heat, so the value is negative, and in HE- 3 the system is cooled, meaning the value is also negative. In HE-1, the temperature value is positive (representing heat into the system). In HE-2, the system rejects heat, thus the value is negative. In the same way, in HE-3, the system is cooled, and the value is also negative.

$$Q_c = \dot{m}_w\ Cp_w\ (T_{w-o} - T_{w-i}) \tag{4}$$

To balance heat generated in the CPU simulation unit and heat released in HE-1, and cooling working fluid either directly with block HE-3-TEC integrated system or indirectly through intercooler cylinder, as presented in the (eq-5).

$$Q_g = Q_r + Q_c \tag{5}$$

Assume all flexible joints are insulated.

To determine the efficiency of HE-1 by employing the equation below [28], [29];

$$\eta_{HE-1} = \frac{Q_r}{Q_g} = \frac{\dot{m}_w \ \ Cp_w \ (T_{w-o} - T_{w-i})}{V \ \ I} \tag{6}$$

Where the efficiency of heat transform from the source (CPU simulation) to its coolant water is less than 100% because of the difference in heat balance, the diffusivity of HE material and the low conductivity of thermal past (about 2.0 $W/m.K$) .

To determine the cooling capacity through the TEC system, as it can be calculated through (eq-4). It was assumed that all heat removed from working fluid was absorbed by the cold surface of TEC through a block heat exchanger and thermal past, so (eq-4) becomes as follows;

$$Q_c = Q_{w-TEC} = \dot{m}_w \ \ Cp_w \ \ (T_{w-o} - T_{w-i}) \tag{7}$$

Also the heat removed at the cold junction surface for the TEC can be determined by [30];

$$Q_{c-TEC} = 2N\left[SIT_c - \frac{1}{2}I^2\frac{\rho}{G} - \kappa G\Delta T\right] \tag{8}$$

$$Q_{c-TEC} = 2N\left[PI - \frac{1}{2}I^2\frac{\rho}{G} - \kappa G\Delta T\right] \tag{9}$$

Each Joul effect and thermal conductivity of the semiconductors reduced the cooling capacity of the TEC.

For the TEC1-12706-T200, all variables in the equation above are evaluated at an average of measuring temperature [31], so, the values of the variables change according to the working conditions.

$$\left.\begin{aligned} S_m &= 2Ns \\ R_m &= 2N\frac{\rho}{G} \\ K_m &= 2NGK \end{aligned}\right\} \tag{10}$$

where, s, ρ, κ are the physical properties of the material for TEC, while S_m, R_m *and* K_m are the physical characteristic of the TEC cell as device. So it can rewrite (eq-8) as;

$$Q_{c-TEC} = S_m \, I \, T_c - \frac{1}{2} \, I^2 R_m - K_m \, \Delta T \tag{11}$$

$$Q_{h-TEC} = S_m \, I \, T_h + 0.5 \, I^2 R_m - K_m \, \Delta T \tag{12}$$

$$P_{TEC} = IV|_{TEC} \tag{13}$$

So it can be written the power balance equation

$$P_{TEC} = Q_{h-TEC} - Q_{c-TEC} \tag{14}$$

Energy consumption should be prepared as low as possible to ensure the main cooling system works successfully.

Therefore, it is important to operate the TEC not at its maximum cooling capacity but near the optimum coefficient of performance [30], or which is achieved at the optimum current [32], [33].

$$\left.\begin{aligned} C.O.P &= \frac{Q_{c-TEC}}{P_{TEC}} \\ C.O.P_{opt} &= \frac{T_c\left[\sqrt{1 + Z\,T_{ave}} - \frac{T_h}{T_c}\ \right]}{(T_h - T_c)\left[1 + \sqrt{1 + Z\,T_{ave}}\right]} \end{aligned}\right\} \tag{15}$$

$$I_{opt} = \frac{[\kappa \, \Delta T \; G(1 + (1 + ZT_{ave})^{0.5})]}{S \; T_{ave}} \tag{16}$$

While determining current ratio for the TEC element I/I_{max} , thus I_{max} is defined by (eq-17,18) [32]:

$$I_{max} = \left(K\frac{G}{S}\right)\left[\left(1 + (2Z\,T_h)\right)^{1/2} - 1\right] \tag{17}$$

$$V = 2N\left[\left(\frac{I\,\rho}{G}\right) + (S\,\Delta T)\right] \tag{18}$$

To calculate the efficiency of the block HE-3 for cooling the working fluid, (eq-19) is employed [28].

$$\eta_{HE-3} = \frac{Q_c}{Q_{TEC}} = \frac{\dot{m}_w \ \ Cp_w \ (T_{w-o} - T_{w-i})}{2N[SIT_c - \frac{1}{2}I^2\frac{r}{G} - KG\Delta T]} \tag{19}$$

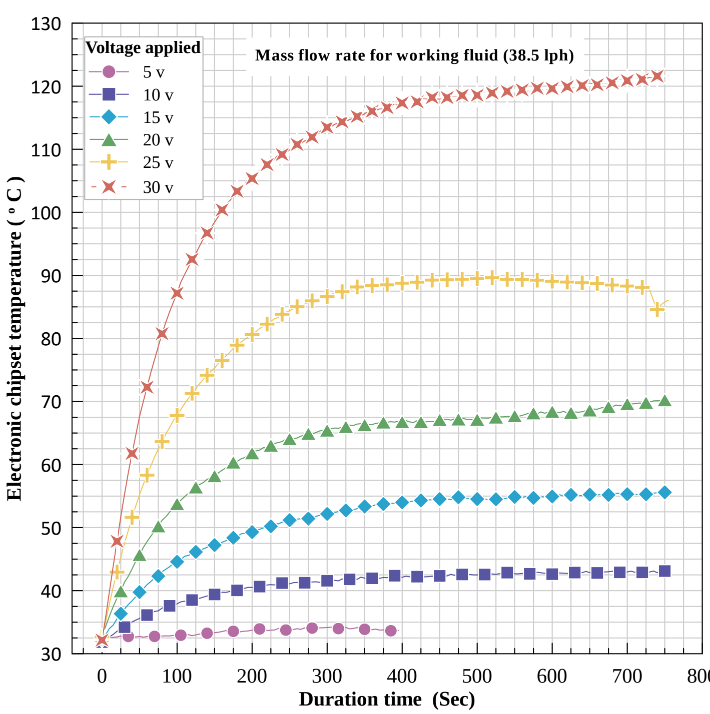
6. Result and discussion

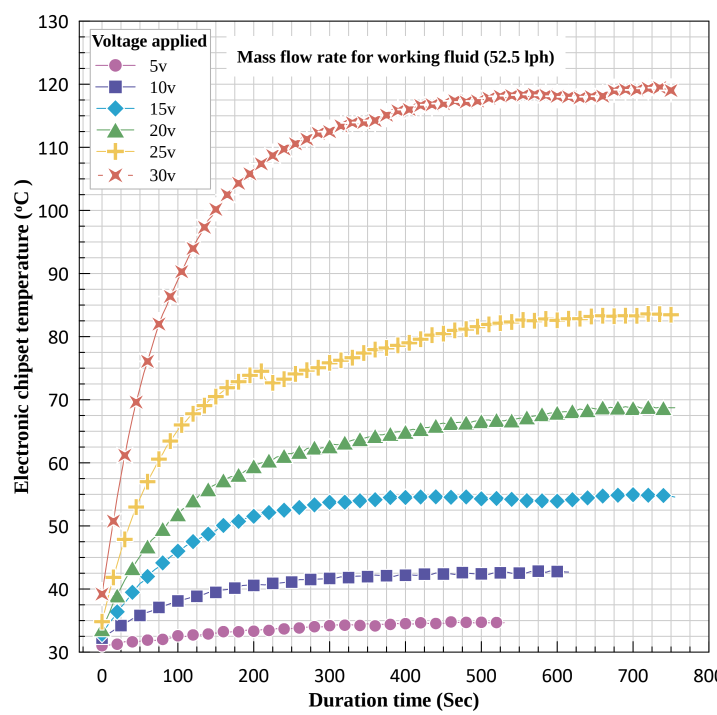
The efficiency of HE-3 becomes lower than HE-1 due to the transfer of heat from the hot surface to the cold surface of TEC with the effect of the type of cooling of the hot surface. After conducting preliminary experiments to cool the CPU simulation unit traditionally through a forced air heat sink, it was found that there was a significant Temperature change that could lead to damage to the central processing unit or negatively affect its working efficiency. Therefore, a water-air heat exchanger was used (see Fig. 1). The results of the tests for Case-1, under the specified test conditions, showed that the use of this system is effective within the thermal capabilities that reach up to 96 watts, as demonstrated for the temperatures fig-2 at the applied voltage of 25 on the electrical heater. The results show that the flow rate of the working fluid has a small effect, taking into account the impact of the temperature of the test space (29-32 °C). It was found that there is a difference in the temperature of the CPU simulation unit when it operates at a thermal generation rate of 145 Watts. Figure 3 shows the effect of the flow rate of the working fluid on the amount of heat released at different levels of heat generation. This effect is due to the temperature of the test space, where the amount of heat gained at the applied voltages of 5, 10, and 15 is less than the amount of heat generated. This is a critical case, as the temperature of the working fluid at heat exchanger-2 decreases due to the significant temperature difference. In contrast the temperature difference at the first heat exchanger decreases. This leads to an increase in the temperature of the CPU simulation unit (i.e. its heat storage temperatur).

In addition to the direct effect of the thermal paste in the first heat exchanger, this can be evident from the efficiency of the heat exchanger, which was determined in a range of (82-88%). It was found that increasing the flow rate has a clear impact effect by reducing the temperature of the CPU simulation unit while increasing the amount of heat gained from it, as shown in Figure 3. Therefore, a flow rate of 73 lph will be adopted in subsequent tests. The results of Case-2 showed that the power consumption of the thermoelectric cooling unit led to a reduction in the temperature of the central processor simulation unit by 5.2%, or by 6 °C, as illustrated in Figure 4. The results for Case-3 showed a decrease in the temperature of the central processor simulation unit by 11.3%, which is double the percentage reduction observed for Case-2, with approximately the same power consumer. The working fluid was cooled within the intercooling cylinder, which provides the initial cooling for a larger quantity than the working quantity. This means that the heat generated in the central processor simulation unit is removed effectively, even with increases due to the use of programs or graphics, which lead to higher working frequencies.

Figure 5 shows a decrease in the temperature of the CPU simulation unit, in addition to the amount of heat gained from heat exchanger HE-1 and the heat released from HE-2 due to the effect of TEC. Using Eq-5, clear balance is observed in reducing the amount of heat in the cooled water through the TEC when fed with 6 volts, which is close to the optimal performance voltage. Moreover, feeding the TEC with a higher voltage requires removing heat from its hot side surface. The optimal current was 0.761 amps, and the optimal performance factor was 3.62. The performance factor for the operating system was 1.76. This value indicates that the system is approaching the optimal performance range, and the low temperature difference between the hot and cold surfaces [34]- [36]. A cooling capacity of 28.6 watts was attained, with values achieved at a maximum current of 6 amperes [36] and a working current of 2.7 amps.

6.1. case-1 (a) **(b)**





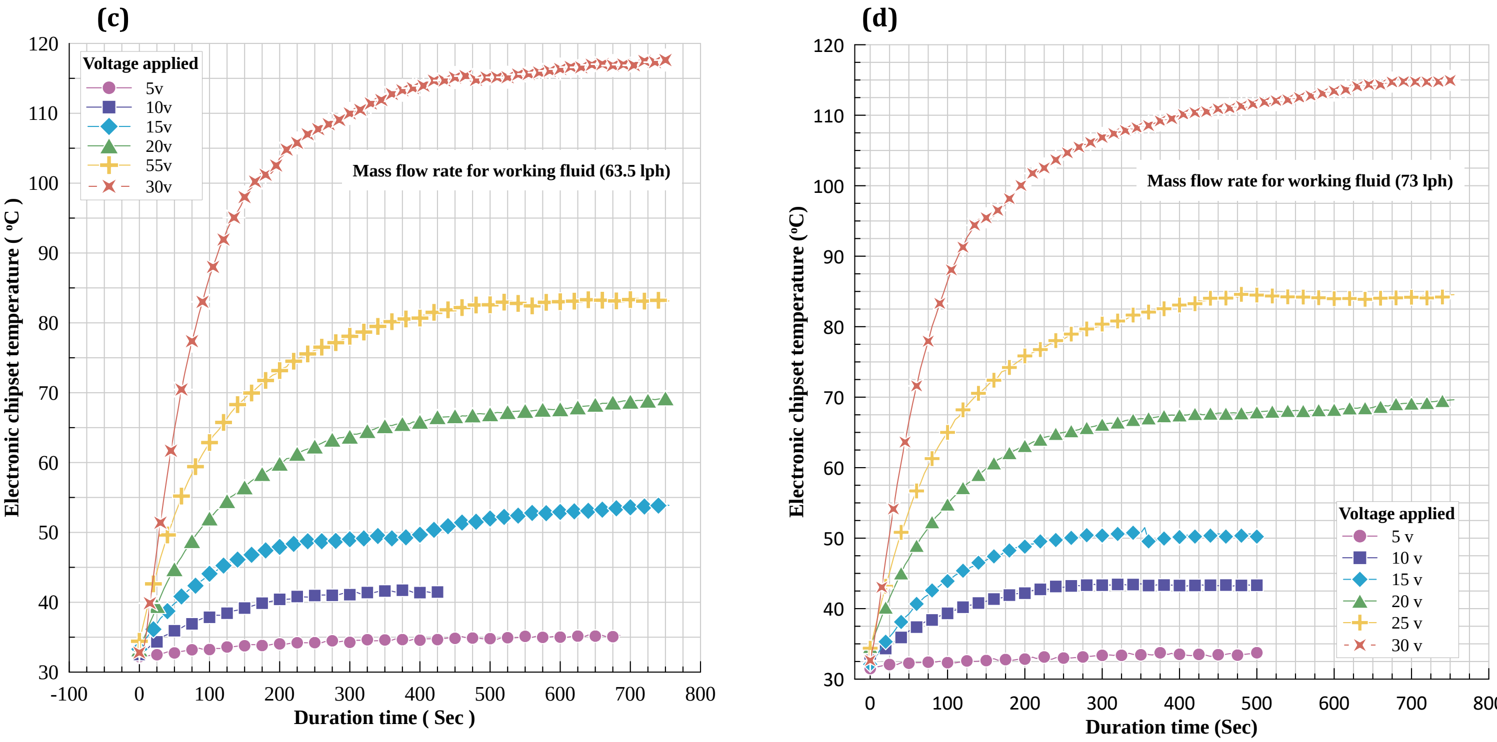
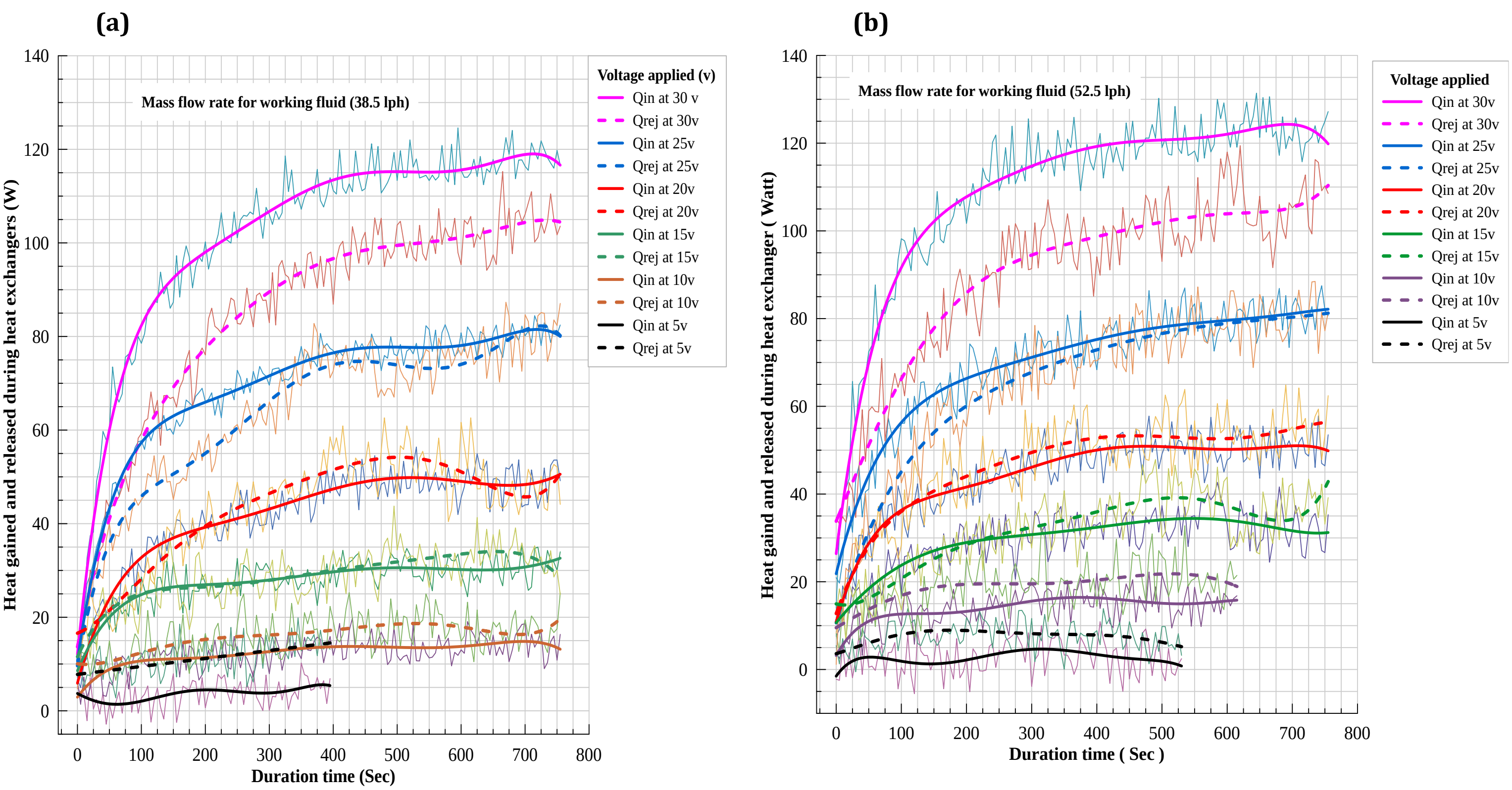


Figure 2; CPU simulation unit temperature for different applied voltages and working fluid flow rate.

6.2. case-1 Heat generated and released



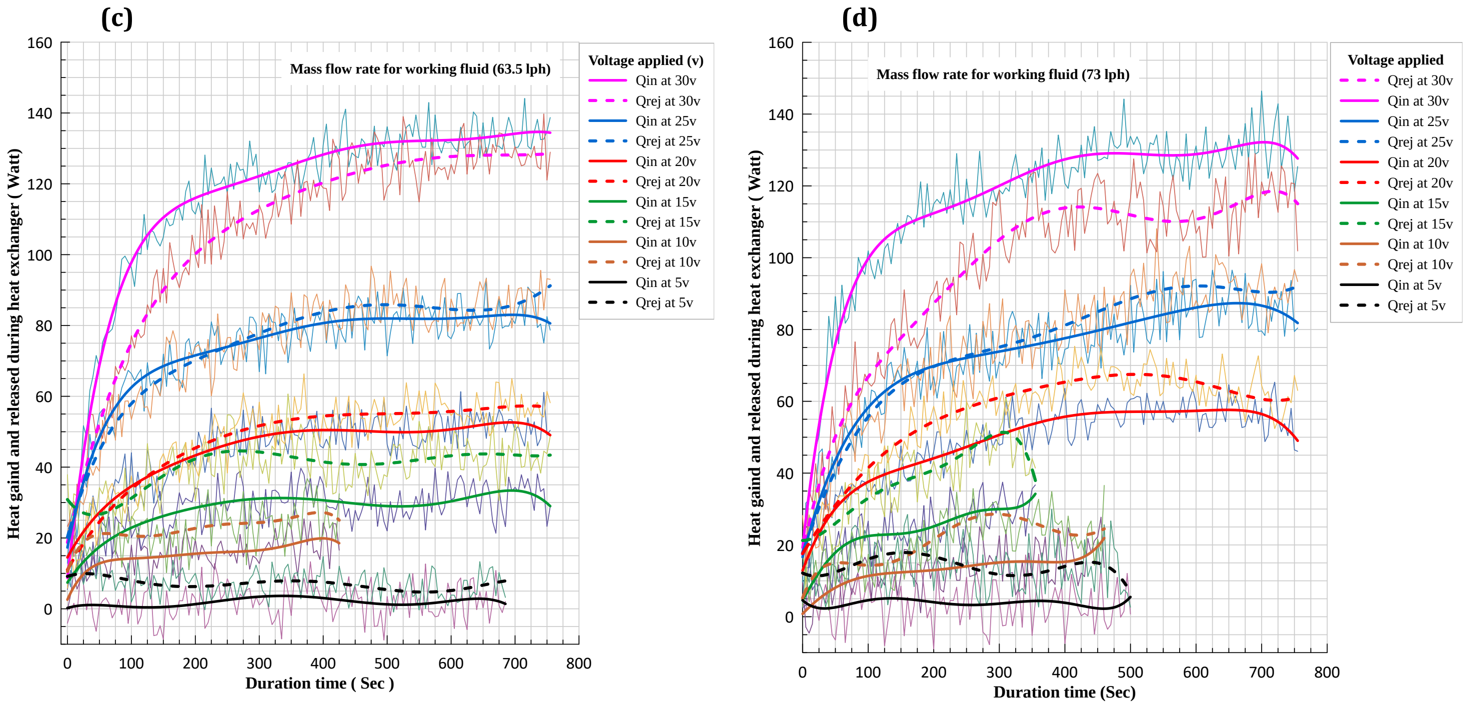


Figure 3; The amount of heat gained from the CPU simulation unit by HE-1 and released by HE-2.

6.3. Compression result

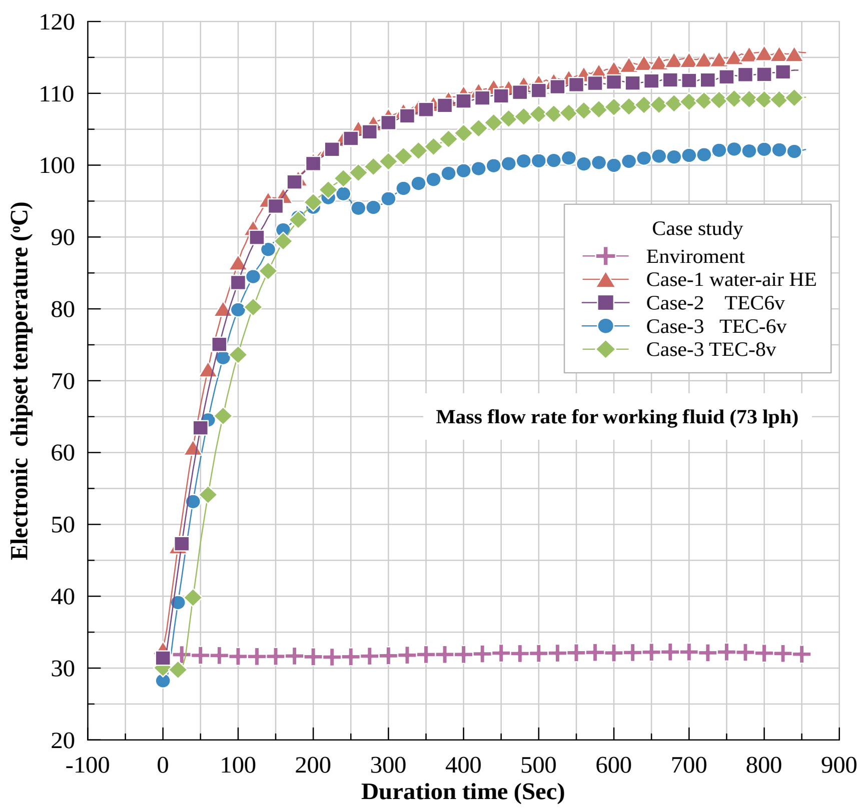


Figure 4; Comparison of CPU simulation unit temperature for cases-1,2,3.

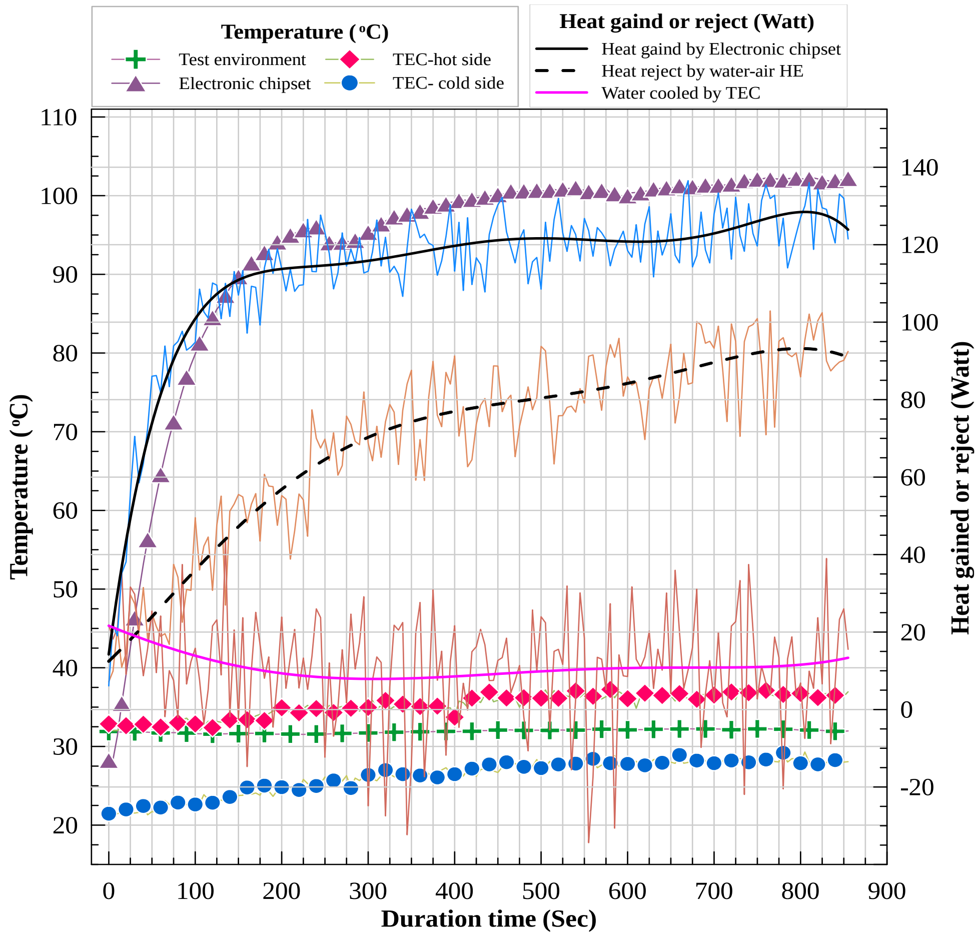


Figure 5; Results of the effect of employing a TEC unit and an intercooler cylinder.

7. Conclusion

The second developed hybrid cooling system represents a safety point specifically for computers whose CPU and GPU operate at different speeds and high frequencies, which allows them to be cooled by the presence of a primary working liquid cooled to relatively low temperatures and in pre-stored quantities, which distinguishes them from all the traditional coolers used. In particular, the effective use of successive cooling systems emphasizes the significance of continuous invention in thermal management applications. There is a need for progressive cooling technologies/systems, leading to an increase power and compact of the electronic devices. Therefore, upcoming growth research in this field should emphasize more improving the efficiency of cooling systems, incorporating clever thermal management methods, and searching new materials to obtain even better performance advances and confirm the durability of electronic chipsets.

The most important thing that was concluded during the current experimental research is the mechanism of operation of the hybrid cooling system, which led to a significant reduction in the temperature of the computer processor simulation unit through the employment of three sequential stages, which are:

- Transferring heat from the working fluid to the space Using little energy
- Employing an intercooler cylinder with a sizeable working fluid capacity, which ensures cooling of the processor unit when operating at high frequencies
- Using thermoelectric cooling within an acceptable coefficient of performance (by moving away from the maximum cooling capacity), which requires a special system to dissipate heat from the hot surface in addition to a decrease in the coefficient of performance, which means a high energy west,

so this can be replaced by employing more than one module of thermoelectric cooling with acceptable cooling capacity and low energy consumption. The above observation expresses the importance of the current work.

Nomenclature

A	Area (m^2)
CPU	Central processor unit
GPU	Graphical processor unit
TEC	Thermoelectric cooler
Q	Heat flow rate (Watt)
Q_c	Cooling capacity (Watt)
Q_{c-TEC}	Cooling capacity by TEC (Watt)
Q_g	Heat generated by the electric heater (Watt)
Q_r	Heat released (Watt)
Q_{w-TEC}	Capacity of cooling water by TEC (Watt)
N	Number of TEC element
S	Seebeck coefficient (V/K)
ρ	Electrical resistivity ($\Omega\ cm$)
T	Temperature (K)
ΔT	Temperature difference ((K)
T_c	Cold side temperature of TEC (K)
T_c	Hot side temperature of TEC (K)
K	Thermal conductivity (W/cm.k)
lph	Liters per hour
Z	Figure of merit ($s^2/(\rho\ \kappa)$) (k^{-1})
ZT	Dimensionless figure of merit
G	Geometry factor of TEC (area /length) (cm)
P	Peltier coefficient ($P = S * T_c$)
P	Power (W)
C.O.P	Coefficient of performance
I	Current (amp)
S_m	Device seebeck voltage (V/K)
R_m	Device electrical resistance (Ohm)
K_m	Device thermal conductivity (W/K)
	Sub
opt	Optimum value

Funding

None.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. W. P. N. A. Siricharoenpanich, "Study on the thermal dissipation performance of GPU cooling system with nanofluid as coolant," *Case Studies in Thermal Engineering,* vol. 25, no. 2, pp. 1-10, February 2021, https://doi.org/10.1016/j.csite.2021.100904.

[2] C. L. a. H. Yu, "Experimental Investigations on Heat Transfer Characteristics of Direct Contact Liquid Cooling for CPU," *buildings,* vol. 12, no. 6, pp. 1-16, June 2022, https://doi.org/10.3390/buildings12070913

[3] N. A. C. S. Muhammad Arif Harun and, "A Review on Development of Liquid Cooling System for Central Processing Unit (CPU)," *Journal of Advanced Research in Fluid,* vol. 78, no. 2, pp. 98-113, 2021, https://doi.org/10.37934/arfmts.78.2.98113.

[4] N. S. S. G. I. T. C.A. Gould, "Thermoelectric cooling of microelectronic circuits and waste heat electrical power generation in a desktop personal computer," *Materials Science and Engineering B,* vol. B 176, no. 9, p. 316–325, September 2011, doi:10.1016/j.mseb.2010.09.010.

[5] L. G. A. ,. S. W. Nizar Ahammed, "Thermoelectric cooling of electronic devices with nanofluid in a multiport minichannel heat exchanger," *Experimental Thermal and Fluid Science,* vol. 74, no. 12, pp. 81-90, December, 2016, http://dx.doi.org/10.1016/j.expthermflusci.2015.11.023.

[6] y. a. X. M. S. B. Riffatn, "Improving the coefficient of performance of thermoelectric cooling systems: a review," *NTERNATIONAL JOURNAL OF ENERGY RESEARCH,* vol. 28, no. 9, p. 753–768, June 2004, DOI: 10.1002/er.991.

[7] G. T. Dongliang Zhao, "A review of thermoelectric cooling: Materials, modeling and applications," *Applied Thermal Engineering,* vol. 66, no. 2, p. 15e24, February 2014, http://dx.doi.org/10.1016/j.applthermaleng.2014.01.074.

[8] A. D. A. M. J. H. H. K. E. David Martínez-Maradiaga, "Design and testing of topology optimized heat sinks for a tablet," *International Journal of Heat and Mass Transfer,* vol. 142, no. July, pp. 1-12, 2019, .

[9] S. W. A. S. P. N. A. Siricharoenpanich, "Thermal management system of CPU cooling with a novel short heat pipe cooling system," *Case Studies in Thermal Engineering,* vol. 15, no. 10, pp. 1-8, October 2019, https://doi.org/10.1016/j.csite.2019.100545.

[10] W. L. W. D. L. Q. &. C. Z. G. Sun, "Advances in Thermoelectric Devices for Localized," *Elsevier B.V.,* vol. 450, no. 4, pp. 1-50, 2022,

[11] K.-L. L. ,. C. T. ,. Y. K. ,. R. K. Cho-Ning Huang, "Computational fluid dynamics model for a variable conductance thermosyphon," *Case Studies in Thermal Engineering,* vol. 25, no. 3, pp. 1-17, March 2021, https://doi.org/10.1016/j.csite.2021.100960.

[12] H.-H. W. C.-C. C. S.-L. C. Te-En Tsai, "Two-phase closed thermosyphon vapor-chamber system for electronic cooling," *International Communications in Heat and Mass Transfer,* vol. 37, no. 2, pp. 484-489, February 2010.

[13] J.-C. Wang, "Superposition method to investigate the thermal performance of heat sink with embedded heat pipes," *International Communications in Heat and Mass Transfer,* vol. 36, no. 5, p. 686–692, May 2009, doi:10.1016/j.icheatmasstransfer.2009.04.008.

[14] H.-S. H. S.-L. C. Jung-Chang Wang, "Experimental investigations of thermal resistance of a heat sink with horizontal embedded heat pipes," *International Communications in Heat and Mass Transfer,* vol. 34, no. 5, p. 958–970, may 2007, doi:10.1016/j.icheatmasstransfer.2007.03.015.

[15] D. W. G. P. Ji Li, "Experimental studies on a high performance compact loop heat pipe with a square flat evaporator," *Applied Thermal Engineering,* vol. 30, no. 12, p. 741–752, December 2010, doi:10.1016/j.applthermaleng.2009.12.004.

[16] D. M. J. C. Sukhvinder Kang, "CLOSED LOOP LIQUID COOLING FOR HIGH PERFORMANCE COMPUTER SYSTEMS," in *Proceedings of IPACK2007, ASME InterPACK '07*, July 8-12, 2007, Vancouver, British Columbia, CANADA, 2007.

[17] R. Andrzejczyk, "Experimental Investigation of the Thermal Performance of a Wickless Heat Pipe Operating with Different Fluids: Water, Ethanol, and SES36. Analysis of Influences of Instability Processes at Working Operation Parameters," *MDPI-energies,* vol. 80, no. 12, pp. 1-28, December 2019, doi:10.3390/en12010080.

[18] S. W. S. W. P. Naphon, "Application of two-phase vapor chamber technique for hard disk drive cooling of PCs," vol. 40, no. 10, pp. 32-35, October 2013.

[19] Q. Z. S. Z. F. M. L. L. Sheng Du, "Simulation analysis on energy consumption and economy of CPU cooling system based on loop heat pipe for data center," *Thermal Science and Engineering Progress,* vol. 45, no. 9, pp. 1-15, September 2023.

[20] S. C. R. Rachedi, "Enhancement of electronic cooling by insertion of foam material," *Heat and Mass Transfer ,* vol. 37, no. 7, pp. 371-378, 2001.

[21] E. A. G. Suwat Trutassanawin, "Numerical Analysis of a Miniature-Scale Refrigeration System (MSRS) for Electronics Cooling," in *International Refrigeration and Air Conditioning*, Purdue e-Pubs, 2004.

[22] T. T. S. T. S. H. Takayuki Atarashi, "Calculation Method for Forced-Air Convection Cooling Heat Transfer Coefficient of Multiple Rows of Memory Cards," *Journal of Electronics Cooling and Thermal Control,* vol. 4, no. 9, pp. 70-77, 2014.

[23] H. M. A. M. M. J. W. P. C. L. M. A. Muhammad Aamer Hayat, "Phase change material/heat pipe and Copper foam-based heat sinks for thermal management of electronic systems," *Journal of Energy Storage,* vol. 32, no. 10, pp. 1-11, October 2020, https://doi.org/10.1016/j.est.2020.101971.

[24] R. J. G. B. A. R. F.M. Naduvilakath-Mohammed, "Closed loop liquid cooling of high-powered CPUs: A case study on cooling performance and energy optimization," *Case Studies in Thermal Engineering,* vol. 50, no. 9, pp. 1-15, 2023, https://doi.org/10.1016/j.csite.2023.103472,

[25] M. A. E. B. A. T. M. P.-F. M. S. Elnaz Etminan, "On the performance of an innovative electronic chipset thermal management module based on energy storage unit concept utilizing nano-additive phase change material (NPCM)," *Journal of Energy Storage,* vol. 50, no. 2, pp. 1-13, February 2022.

[26] P. S. K. Domke, "Peltier modules in cooling systems for electronic components," *Advanced Computational Methods and Experiments in Heat Transfer XI,* 2010, doi:10.2495/HT100011.

[27] Y. A. Cengel, Heat and Mass Transfer A Practical Approach, Tata McGraw Hill, 2007.

[28] A. Fakheri, "Heat Exchanger Efficiency," *Transactions of the ASME,* vol. 129, no. 9, pp. 1268-1276, SEPTEMBER 2007.

[29] A. Çağlar, "Optimization of operational conditions for a thermoelectric refrigerator and its performance analysis at optimum conditions," i*nternational Journal of Refrigeration,* vol. 96, no. 12, pp. 70-77, 2018.

[30] A. M. R. P. Maciel, "Development and Control of a condensation system using Peltier Cells," M.S. thesis, Electrical and Computer Engineering, TECNICO,LISBOA, 2014.

[31] C. M. Jaworski, "OPPORTUNITES FOR THERMOELECTRIC ENERGY CONVERSION IN HYBRID VEHICLES," Department of Mechanical Engineering The Ohio State University , Ohio State, 2007.

[32] MeLCOR, Thermoelectric Handbook, The Standard in Thermoelectrics, Trenton, USA: melcor.

[33] E. S. Jeong, "A new approach to optimize thermoelectric cooling modules," *Cryogenics,* vol. 59, no. 12, pp. 38-43, December 2014.

[34] J. Mao, G. Chen and Z. Ren, "Thermoelectric cooling materials", Nature material, Prespective, 09 December 2020.

[35] N. Korprasertsak , T. Leephakpreeda, " Maximizing cooling/heating performance of thermoelectric modules across variable thermal loads via optimal control based on COP curves", Heliyon, vol.10, no.1, pp. 1-11, January,2024,

[36] Specification of Thermoelectric Module TEC1-12706," High Performance and Highly Reliable Solution for Cooling and Heating Applications", Web Site: www.thermonamic.com.cn